Probing TMDs through azimuthal distributions of pions inside a jet in hadronic collisions [1]

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Abstract

The azimuthal distributions around the jet axis of leading pions produced in the jet fragmentation process in pp collisions are studied within the framework of the so-called generalized parton model. The observable leading-twist azimuthal asymmetries are estimated in kinematic configurations presently investigated at RHIC. It is shown how the main contributions coming from the Collins and Sivers effects can be disentangled. In addition, a test of the process dependence of the Sivers function is provided.

The process $p^\uparrow p \to \mathrm{jet}\,\pi + X$, where one of the protons is in a transverse spin state and the jet is produced with a large transverse momentum, $p_{\mathrm{j}T}$, is studied within the framework of the generalized parton model (GPM), in which factorization is assumed and spin and intrinsic parton motion effects are taken into account [1]. In this approach, azimuthal asymmetries in the distribution of leading pions around the jet axis are given by convolutions of different transverse momentum dependent distribution and fragmentation functions (TMDs). Similarly to the case of semi-inclusive deep inelastic scattering (SIDIS), it is possible to single out the different contributions by taking appropriate moments of such asymmetries. This would be very useful in clarifying the role played mainly by the Sivers distribution and the Collins fragmentation function in the sizeable single spin asymmetries observed at RHIC for single inclusive pion production, where these underlying mechanisms cannot be disentangled.

The single-transverse polarized cross section for the process under study has been calculated at leading order in pQCD utilizing the helicity formalism and has the general structure [1]

$$2\mathrm{d}\sigma(\phi_S, \phi_\pi^H) \sim \mathrm{d}\sigma_0 + \mathrm{d}\Delta\sigma_0 \sin\phi_S + \mathrm{d}\sigma_1 \cos\phi_\pi^H + \mathrm{d}\sigma_2 \cos 2\phi_\pi^H$$

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[1]Talk given by C.P. at 20th International Symposium on Spin Physics (SPIN2012), JINR, Dubna (Russia), 17 - 22 September 2012.
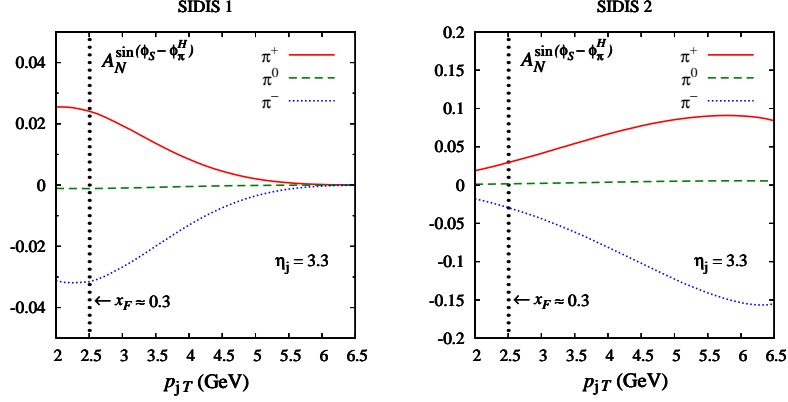
Figure 1: The Collins asymmetry $A_N^{\sin(\phi_S - \phi_\pi^H)}$ as a function of p_{jT}, at fixed jet rapidity $\eta_j = 3.3$ and energy $\sqrt{s} = 200$ GeV.

$$+ \,\mathrm{d}\Delta\sigma_1^- \sin(\phi_S - \phi_\pi^H) \,+\, \mathrm{d}\Delta\sigma_1^+ \sin(\phi_S + \phi_\pi^H)$$
$$+ \,\mathrm{d}\Delta\sigma_2^- \sin(\phi_S - 2\phi_\pi^H) \,+\, \mathrm{d}\Delta\sigma_2^+ \sin(\phi_S + 2\phi_\pi^H)\,, \quad (1)$$

where ϕ_S is the angle of the proton transverse spin vector S relative to the jet production plane, and ϕ_π^H is the azimuthal angle of the pion three-momentum around the jet axis, as measured in the fragmenting parton helicity frame [1]. The various angular modulations can be projected out by defining the azimuthal moments

$$A_N^{W(\phi_S,\phi_\pi^H)} = 2\,\frac{\int \mathrm{d}\phi_S \mathrm{d}\phi_\pi^H\, W(\phi_S,\phi_\pi^H)\,[\mathrm{d}\sigma(\phi_S,\phi_\pi^H) - \mathrm{d}\sigma(\phi_S + \pi,\phi_\pi^H)]}{\int \mathrm{d}\phi_S \mathrm{d}\phi_\pi^H\,[\mathrm{d}\sigma(\phi_S,\phi_\pi^H) + \mathrm{d}\sigma(\phi_S + \pi,\phi_\pi^H)]}\,, \quad (2)$$

with $W(\phi_S, \phi_\pi^H)$ being one of the circular functions of ϕ_S and ϕ_π^H in (1).

The upper bounds of all these different asymmetries have been evaluated for RHIC kinematics and can be found in [1]. In the following only those (sizeable) effects are considered, that involve TMDs for which parameterizations are available from independent fits to SIDIS, Drell-Yan (DY), and e^+e^- data. The asymmetry $A_N^{\sin(\phi_S - \phi_\pi^H)}$ is given mainly by the convolution of the transversity distribution and the Collins fragmentation functions. It is shown in Fig. 1 in the forward rapidity region adopting two different sets of parameterizations (SIDIS 1 and SIDIS 2) [1]. Preliminary RHIC data [2] are in agreement with our prediction of an almost vanishing Collins asymmetry for neutral pions. The quark and gluon contributions to the Sivers asymmetry $A_N^{\sin\phi_S}$, which cannot be disentangled, are presented in Fig. 2 in the same
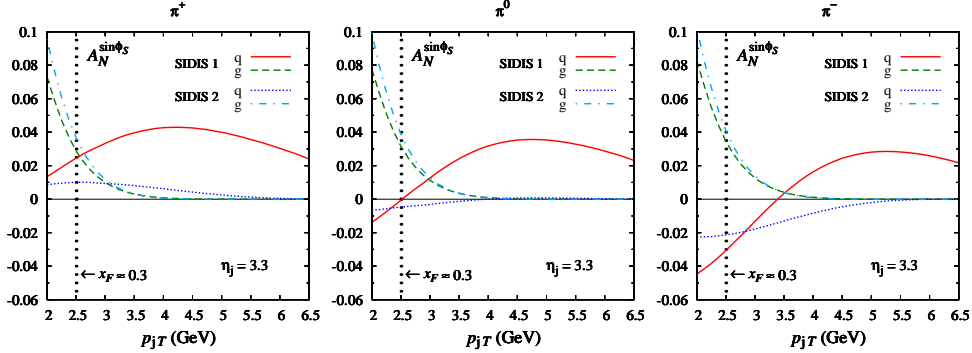
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Figure 2: Same as in Fig. 1 but for the Sivers asymmetry $A_N^{\sin\phi_S}$.

kinematic region. The quark term is obtained utilizing again the SIDIS 1 and SIDIS 2 parameterizations, while the gluon Sivers function is tentatively taken positive and saturated to a bound obtained by considering PHENIX data for inclusive neutral pion production at mid-rapidity [1]. In both figures, the two parameterizations give comparable results only for values of the Feynman variable x_F smaller than 0.3, marked by the dotted vertical lines. Above this limit TMDs are not constrained by present SIDIS data, hence our predictions are affected by large uncertainties. A measurement of these asymmetries would therefore provide very useful information on the large x behaviour of the underlying TMDs.

So far TMDs have been assumed to be universal. In the framework of the color gauge invariant (CGI) GPM [3], one takes into account also the effects of initial (ISI) and final state interactions (FSI) between the active parton and the spectator remnants, which can render the TMDs process dependent. For example, the Sivers functions in SIDIS and DY are expected to have opposite relative signs, due to the difference between FSI and ISI occurring, separately, in the two reactions. This is a decisive prediction (not yet confirmed by experiments) of our present understanding of single spin asymmetries. The quark Sivers function turns out to have a more complicated color factor structure in $p^\uparrow p \to \text{jet}\,\pi + X$, because both ISI and FSI contribute [3]. Nonetheless, in the forward rapidity region only the $qg \to qg$ channel dominates. Therefore, as shown in Fig. 3, our results for the Sivers asymmetries obtained with and without the inclusion of ISI and FSI have comparable sizes but opposite signs, in strong analogy with the DY case. Hence the observation of a sizeable asymmetry could easily discriminate among the two
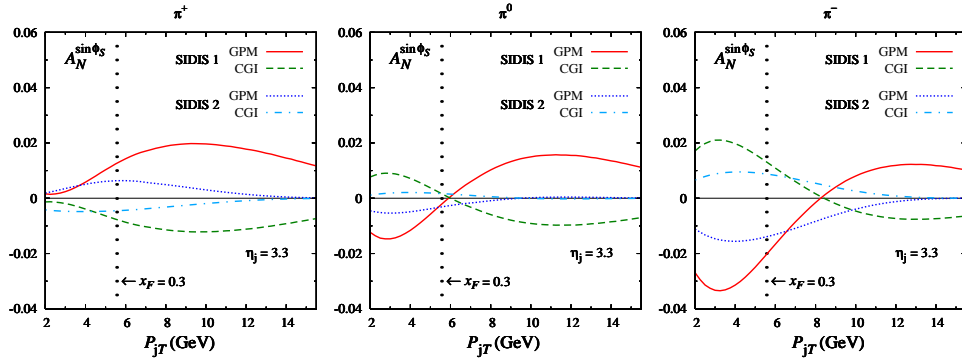
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Figure 3: The estimated quark contribution to the Sivers asymmetry $A_N^{\sin\phi_S}$ as a function of p_{jT}, at fixed jet rapidity $\eta_j = 3.3$ and energy $\sqrt{s} = 500$ GeV.

approaches and test the process dependence of the Sivers function.

To conclude, single-spin asymmetries for inclusive jet production, described only by the Sivers function, have also been analysed [1, 3]. The results obtained for $A_N^{\sin\phi_S}$ look very similar to the ones for jet-neutral pion production presented in the central panel of Fig. 3. According to preliminary data, the Sivers asymmetries for these two processes are small and positive [2, 4]. Further comparison with experiments is needed to confirm the validity of the factorization assumption and test the universality properties of TMDs.

References

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